

WHAT IS CLAIMED IS:

5 1. A three-dimensional steering tool for use in
drilling a borehole in an underground formation in which an
elongated conduit extends from the surface through the
borehole and in which the steering tool is mounted on the
conduit near a drill bit for drilling the borehole, the
10 steering tool comprising an integrated telemetry section,
rotary section and flex section aligned axially along the
steering tool for separately controlling inclination and
azimuth angles at the drill bit; in which the flex section
includes an elongated drive shaft coupled to the drill bit and
15 adapted to be rotatably driven for rotating the drill bit, the
drive shaft being bendable laterally to define a deflection
angle thereof, and a deflection actuator coupled to the drive
shaft, the deflection actuator comprising a deflection housing
surrounding the drive shaft and having a longitudinal axis and
20 an elongated deflection piston movable in the deflection
housing for applying a lateral bending force to the drive
shaft for making changes in the deflection angle of the drive
shaft and which is transmitted to the drill bit as an
inclination angle steering adjustment; in which the rotary
25 section is coupled to the actuator and includes a rotator
actuator for transmitting a rotational force to the deflection
actuator to rotate the deflection piston to thereby change the
rotational angle at which the lateral bending force is applied
to the drive shaft which is transmitted to the drill bit as an
30 azimuth angle steering adjustment; and in which the telemetry
section measures the inclination angle and the azimuth angle
during drilling and compares them with desired inclination and
azimuth angle information to produce inclination control
signals for operating the deflection actuator to make steering
35 adjustments in the inclination angle and for separately

producing azimuth control signals for operating the rotator actuator for making steering adjustments in the azimuth angle.

5 2. Apparatus according to claim 1 in which the conduit is an elongated rotary drill string.

10 3. Apparatus according to claim 1 in which the deflection actuator comprises an elongated deflection housing surrounding the drive shaft, and an elongated hydraulically operated piston in the deflection housing for applying the bending force distributed lengthwise along the drive shaft for flexing the drive shaft laterally to produce said deflection angle thereof to thereby change the inclination angle at the drill bit.

15 4. Apparatus according to claim 3 in which the rotator actuator is coupled to the deflection housing and includes a rotator piston movable in proportion to a desired change in the azimuth angle and a helical gear arrangement on the deflection housing coupled to the rotator piston and rotatable in response to piston travel to rotate the deflection housing to change the azimuth angle at the drill bit.

25 5. Apparatus according to claim 1 in which the hydraulically powered bending force is applied to the deflection piston by drilling mud taken from an annulus between the conduit and the borehole.

30 6. Apparatus according to claim 1 in which the deflection actuator applies the bending force to the drive shaft while the rotary actuator applies the rotational force to the deflection actuator for making simultaneous adjustments in the inclination angles and the azimuth angles.

7. Apparatus according to claim 1 in which the feedback
loop comprises a closed loop controller including a comparator
5 for receiving the measured and desired inclination angle and
azimuth angle command signals for producing inclination and
azimuth error signals for making the steering adjustments.

8. Apparatus according to claim 1 in which the
10 telemetry section comprises an onboard mud pulse telemetry
section for receiving the desired inclination and azimuth
angle input signals and utilizing mud pulse controls for
operating the deflection actuator and the rotator actuator
from drilling mud taken from an annulus between the conduit
15 and the borehole.

9. The apparatus according to claim 8 in which the mud
pulse telemetry section provides open loop control to the
deflection actuator and the rotator actuator, and in which
20 electrical controls provide closed loop control to the
actuators.

10. Apparatus according to claim 1 in which the
deflection actuator includes axially spaced-apart end bearings
25 for mounting the drive shaft along a longitudinal axis of the
steering tool, and a deflection piston for applying the
lateral bending force to the drive shaft between the end
bearings to bend the drive shaft while the end bearings
constrain the drive shaft on opposite sides of the deflection
30 piston.

11. Apparatus according to claim 1 in which the
deflection piston contained in the deflection housing is
positioned on one side of the drive shaft and the drive shaft
35 has a longitudinal axis aligned with a longitudinal axis of

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the deflection housing, and the lateral bending force is
applied by the piston as a unitary force which physically
5 bends the drive shaft to deflect its longitudinal axis away
from the axis of the deflection housing.

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